

Predicting the Evolution of Ecological Diked Wetlands in the Sacramento-San Joaquin Delta

G. Blumensiefel, J. Carder, and J. Todd Wetland Ecosystem Team, Santa Clara Valley Water Board, J. Philip Williams and Associates, D. Reed, University of New Orleans and L. C. Reed, University of New Orleans

Abstract

Over 95% of the once fertile 1.5 million ha freshwater wetlands of the Sacramento-San Joaquin Delta have been leveed and removed from tidal and freshwater interaction. In order to meet one of its major goals, restoring ecosystem health, the CALFED Bay-Delta Program is conducting research in many of these former tidal wetlands by restoring and restoring levees. ACO began to study the leveeability patterns and types of restoration to natural ecological function, and the analyzing historically exposed wetlands that have been reached and restored. Using an interdisciplinary approach, involving scientists of hydrogeology, geomorphological, biological, and ecological processes of wetland systems and progress toward restoration, we are comparing such indicators as ecological habitat loss that were accidentally or purposefully controlled by levee breaching to comparative systems (e.g., dredge material disposal in the low-lying "refuge" wetland sites adjacent to the Delta).

Introduction

Under CALFED Bay-Delta Program's Category III two sub-projects, we are conducting interdisciplinary research on breached levee wetlands in the Sacramento-San Joaquin Delta (Delta). Breaching of levees is among the more restoration approaches being considered to restore some integrity to the Delta wetlands that have been "lost" for agriculture.

Given the extensive changes in salinized streams and processes, ecological integrity and manipulation of water, hydrodynamics, or potability and non-potability species, and density declines in fish populations, there are some questions about the feasibility and possibility of restoration. A high degree of uncertainty and unpredictability is associated with reestablishing undesirable ecological functions to restored wetlands. Much of the direct measurement of functions is difficult, if not impossible. (1) indirect or surrogate "indicators" have not been developed or validated and (2) we don't know what indicators (process, habitat, right development of functions).

The intent of this project is to provide critical information necessary to assess whether hydrodynamics restoration strategies proposed under the CALFED program will provide direct wetland functions to support strategy habitat for endangered fishes, such as juvenile spring-run chinook, salmon and delta smelt, as well as habitat for other aquatic and terrestrial species and other ecological functions. Our problems are:

1. Hydrodynamically altered the physical status, size, and pattern of historic Delta wetland levees.
2. Ecological functions that have persisted and potentially inhibited production of important wetland functions.
3. Develop recommendations of existing strategies and optimal distribution of large restoration initiatives.

Our team includes the ecology expertise of the Wetland Ecosystem Team, University of Washington, with that of coastal marsh hydrogeologists and geomorphologists from the University of New Orleans, and various hydrologists and restoration planners from Philip Williams and Associates. We will also collaborate with the State of California Interagency Ecological Program (IEEP) through the Department of State Resources, monitoring of fish assemblages in the Delta.

Table 1. Historical time-integrated numbers and relative size of fish distribution groups in the Sacramento-San Joaquin Delta sites (1 Italia and 20 sites) as determined by the size of the 100% environmental design record.

Wetland Site	Area (ha)	Number of Fish	Number of Fish	Number of Fish
Wetland Site	Area (ha)	Number of Fish	Number of Fish	Number of Fish
Western Wetlands				
1. Delta-Sacramento River	100	100	100	100
2. Delta-Sacramento River	100	100	100	100
Eastern Wetlands				
3. Delta-Sacramento River	100	100	100	100
4. Delta-Sacramento River	100	100	100	100
Delta-Sacramento River				
5. Delta-Sacramento River	100	100	100	100
6. Delta-Sacramento River	100	100	100	100
7. Delta-Sacramento River	100	100	100	100
8. Delta-Sacramento River	100	100	100	100
9. Delta-Sacramento River	100	100	100	100
10. Delta-Sacramento River	100	100	100	100

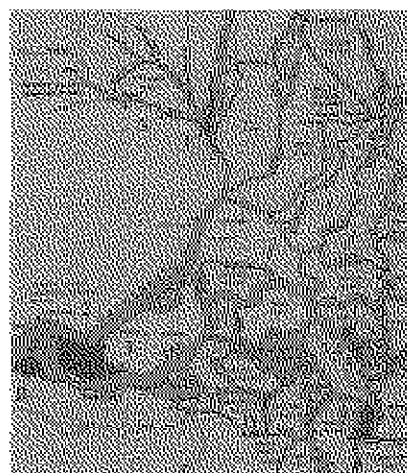


Figure 1. Aerial photograph of the Delta-Sacramento River, showing the levee and the wetland area.

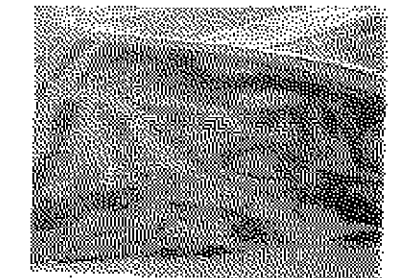


Figure 2. Aerial photograph of the Delta-Sacramento River, showing the levee and the wetland area.

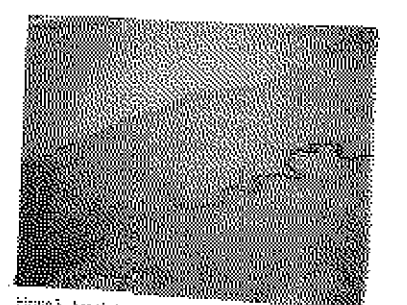


Figure 3. Aerial photograph of the Delta-Sacramento River, showing the levee and the wetland area.

CALFED Bay-Delta Program

The CALFED Bay-Delta Program is a multi-agency, multi-disciplinary effort to develop and implement a long-term comprehensive plan to restore, improve, and protect the Delta and its resources. The program is a partnership between the State of California and the federal government, and is supported by the private sector.

CALFED AGENCIES

CALIFORNIA

- The Resources Agency
- Department of Fish and Game
- Department of Water Resources
- California Department of Transportation
- State Water Resources Control Board

FEDERAL

- Environmental Protection Agency
- Department of the Interior
- Fish and Wildlife Service
- Bureau of Reclamation
- Army Corps of Engineers
- Department of Agriculture

L. of Fisheries, University of Washington, R. Williams and M. Derr
Gallo and Z. Hymanson, California Department of Water Resources

In this manuscript, we focus on the differential importance of selected leadership styles as a "space-for-time substitution" to evaluate economic and their consequences of resources that might be expected from these leadership styles. Figure 3 shows an interesting, but initially rejected, and somewhat mixed evidence that in the 1980s to determine how far it is all three are also important functional supervisory functions (Bass and Stogdill, 1990):

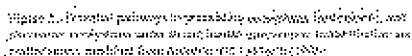
- Over two years, our tasks are for:

- Compute indices of food and nutrient intake quality of three habitats;
- Investigate species' existing utilization and potential interaction with purposefully constructed by three branching of comparable vegetation systems.

Research sites are distributed in the Delta region of spring three different geomorphic settings (Auburn 1989): (1) bottom wetlands including numerous artificial flood levees of the ancestral Sacramento River; (2) former river-levee to brackish wetlands; and (3) coastal wetlands along delta distributaries of the ancestral San Joaquin River (mid channel of Delta 3). We selected seven sites (Figure 2) between between 18 to 60 years since restoration to flood inundation, and spread evenly 1.8 and 2.5 in 6 subwatersheds, and four reference sites (Figure 2) that are considered to be Delta wetlands that have never been leveed.

None consider that any of defined state had more than power, and there is also a trend to see the country only being mentioned in the briefs, and that of the time has been known for those to be a consequence of the state's work, the change in the state's external image is also a result of the state's work, and the change in the state's work is also a result of the state's work.

- [illegible]



Intention to purchase the following products between Fall 1998 and Spring 2000:

Welsh's community analysis of dyadic changes during 1992 was never compared to a simultaneous analysis of 1993 data.

Results: Even sampling and analysis of selected indicators of research functions and institutional patterns and roles in both research and service environments.

Synthesis aspects: modern theory, and scientific and technological education and research patterns and roles of scientific institutions, for the understanding of the probability and time to functional regulation, and technological research and development.

Conclusions: research and service environments, and technological research and development.

1. *Journal of the Royal Society of Medicine*, 1911, 4, 177-178.
2. *Journal of the Royal Society of Medicine*, 1911, 4, 177-178.
3. *Journal of the Royal Society of Medicine*, 1911, 4, 177-178.
4. *Journal of the Royal Society of Medicine*, 1911, 4, 177-178.
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9. *Journal of the Royal Society of Medicine*, 1911, 4, 177-178.
10. *Journal of the Royal Society of Medicine*, 1911, 4, 177-178.

A Conceptual Model of the Geomorphic Evolution of Freshwater Tidal Wetlands within Breached-Levee Sites in the Sacramento-San Joaquin Delta

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Abstract

This study presents a conceptual model of freshwater tidal wetland geomorphic evolution within breached-levee sites in the

Sacramento-San Joaquin Delta.

Breached-levee sites are former natural freshwater tidal wetland areas that were leveed in the past and have now reverted to tidal

action. Some of these sites subsided up to 20 feet during the time they were leveed. Our examination of

breached-levee sites in the Delta indicates that freshwater tidal marsh vegetation quickly colonizes bare ground at intertidal elevations

(within several years). Vegetation establishment through natural processes on deeply subsided, sub-

tidal areas takes significantly

Introduction

Over 95% of the 320,000 acres of historical freshwater tidal wetlands in the Sacramento-San Joaquin Delta have now been leveed. In the past few years, there has been a growing interest in restoring the ecological functions of large areas of the Delta by breaching levees and re-introducing tidal action.

Since most of the potential restoration sites are significantly subsided, up to 20 feet in some

areas, one of the major constraints associated with this type of

restoration is re-building bed elevation faster than the rate of sea level rise. The conceptual model of tidal wetland geomorphic evolution

presented in this poster can be applied in planning future Delta

restoration efforts.

fauna studies. The information presented here is part of an ongoing study and will be refined as the study continues.

Methods

We examined the geomorphic

evolution of six breached-levee

sites and four natural reference sites

in the Delta (Figure 1). Breached-

levee sites are previously-leveed

areas that have been re-flooded,

either intentionally or accidentally.

Reference sites are remnant

portions of wetland that have never

been leveed. We characterized the

following hydrologic and

geomorphic features at some or all

of the sites:

• colonization, expansion, and

erosion of marsh vegetation over

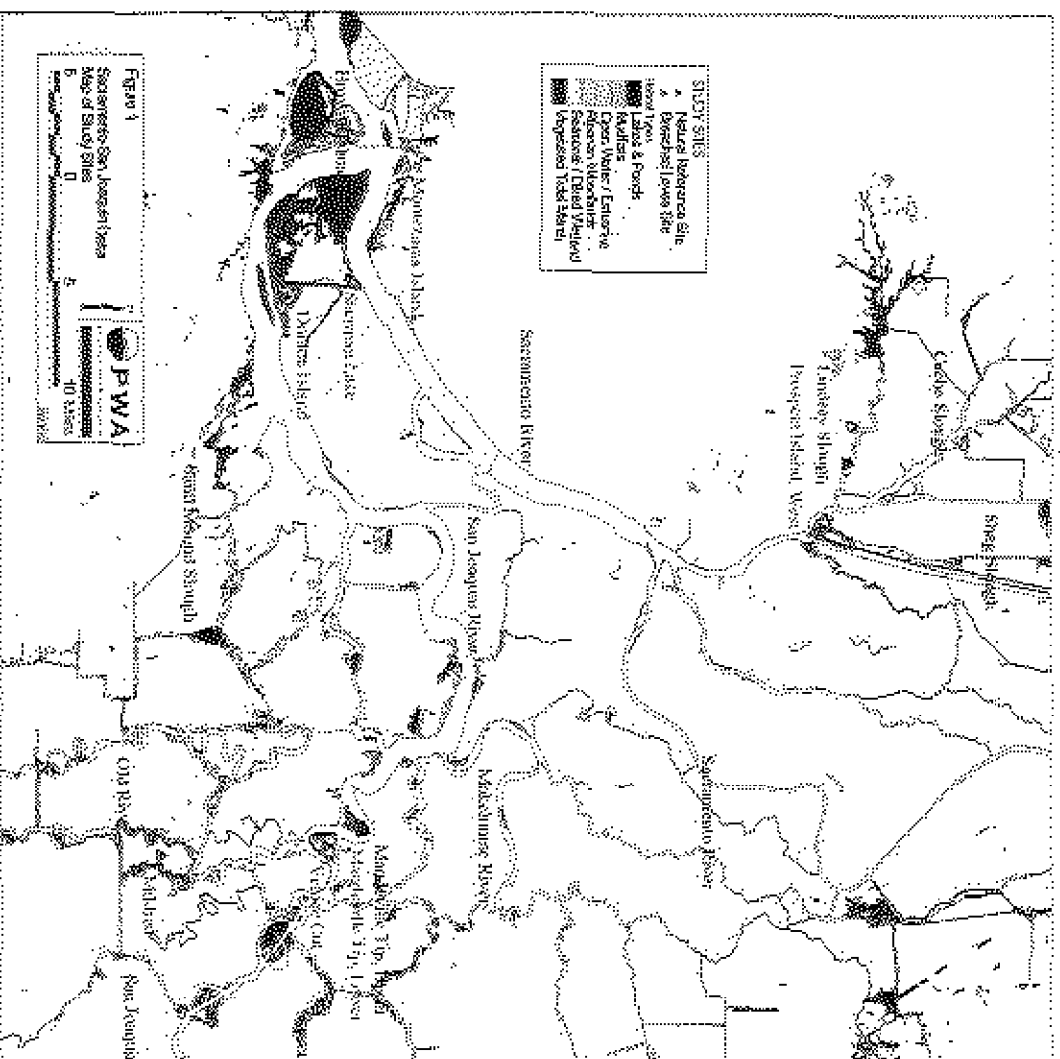
all. Artificial means of raising bed elevations, such as beneficial re-use of dredged materials, accelerates vegetation establishment and may be the only way to ensure restoration of vegetated marsh in deeply subsided sites.

larger study of breached levee Delta wetlands with the University of Washington, California Department of Water Resources, and University of New Orleans that includes sedimentation, fish, invertebrates, and other flora and

- type and elevation of wetland vegetation
- tidal characteristics
- marsh plain elevation

Historical Evolution of the Natural Delta

The original extensive tidal marshplain evolved over the last 5,000 years by transgression -- expanding into lowland floodplain around the Delta perimeter in response to a rising sea level (Atwater *et al.*, 1979). The natural marshplain tends to be at approximately mean higher high water (Figure 2), and keeps pace with sea level rise through sedimentation and organic peat accumulation. Browns Island, the largest remaining natural marsh in the Delta, is shown in Figure 3.

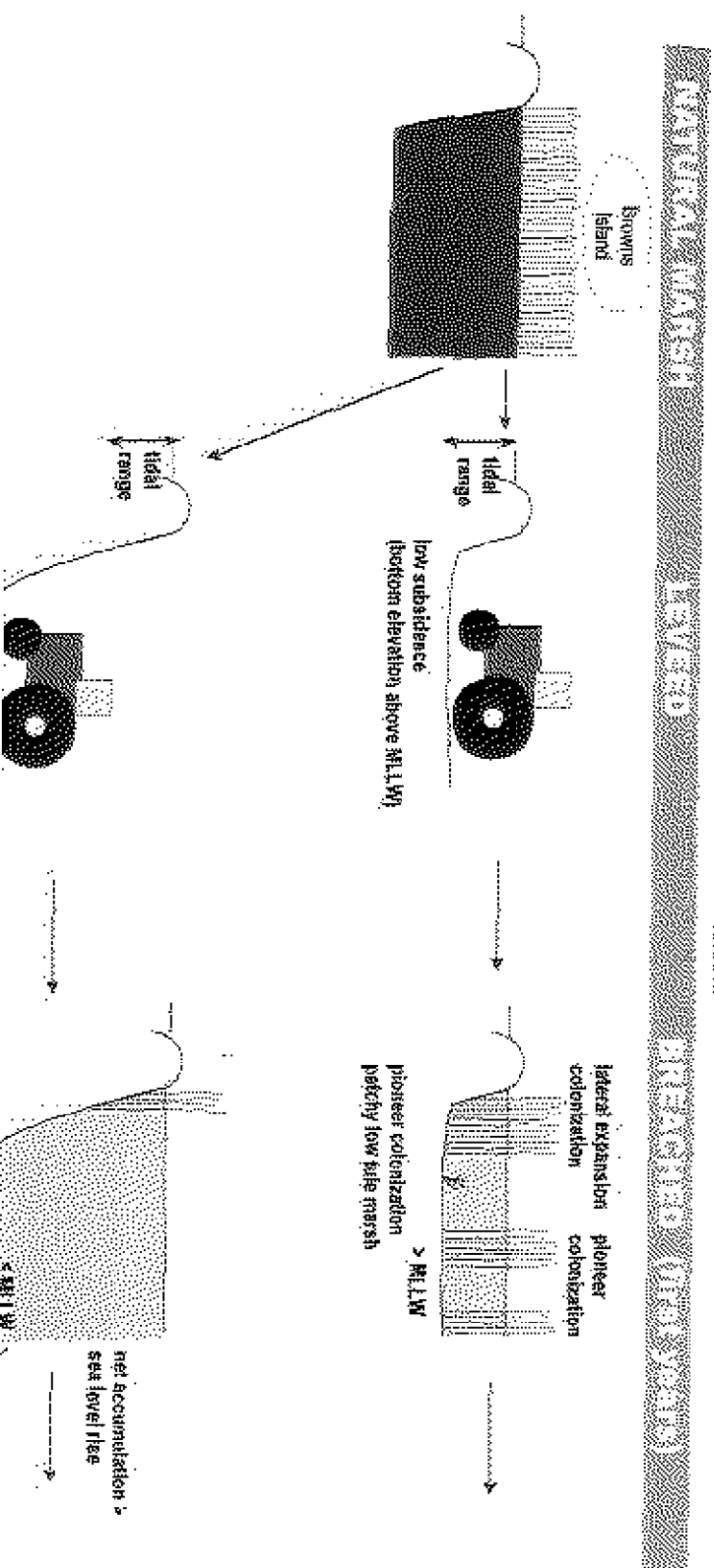


Evolution of Breached-Levee Sites in the Delta

Vegetation colonization of extensive subsided areas requires the build up of bed elevations through sedimentation until vegetation can establish. The conceptual model (Figure 2) predicts the following:

- Once a leveed site is breached, marsh vegetation ("rude") establishes rapidly at intertidal elevations (Figure 4).
- Once established, vegetation spreads to lower elevation areas (approximately two feet below mean lower low water) by lateral colonization from the initial patches. Lateral colonization proceeds at a slow pace (maximum of 5 to 10 feet linear feet/year) and requires sheltered, low wave energy conditions.
- The presence of vegetation promotes subsequent accumulation of both organic and inorganic sediment, though at a relatively slow rate (approximately 0.02 to 0.04 feet/year [6 to 12 mm/year] above the rate of sea level rise).
- The rate of subtidal accumulation in open water areas is slow and may be less than the rate of sea level rise (Figure 5).
- The use of fill, such as dredged material, to raise site elevations results in rapid establishment of marsh vegetation at intertidal elevations (Figure 6).
- Where wave energy is sufficiently high (due to long fetch lengths, boat wakes, etc.), erosion and loss of marsh

Figure 2 Conceptual Model of Freshwater Tidal Wetland Evolution



high subsidence
(bottom elevation below MLLW)

pioneer colonization
on levee perimeter

net
accumulation
sea level rise



figure 3 Browns Island

Browns Island is the largest remaining natural tidal marsh in the Delta and the only site with an extensive branching channel network typical of the historical Delta. Although Browns Island is slightly brackish, it provides one of the best analogues of the Delta's historically vast areas of freshwater tidal marshes.

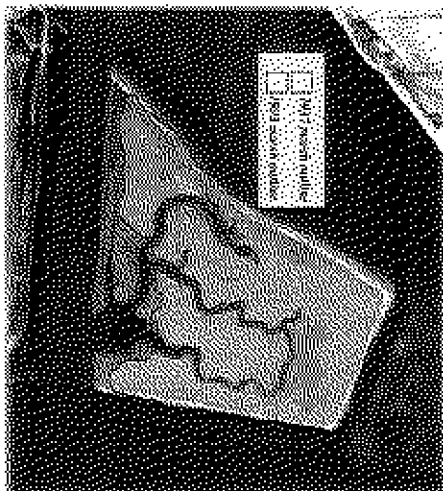


figure 4 Lower Mandeville Tip

Lower Mandeville Tip provides an example of rapid re-vegetation at a shallowly-subsided site following breaching. The majority of the site was at intertidal elevations when it breached in 1933. This aerial photograph, taken in 1937, shows nearly complete re-vegetation four years later. The photograph also shows significant erosion between 1937 and 1993 in the southern part of the site, where wave energy is high along the Stockton Deep Water Ship Channel.



figure 5 Mildred Island

Mildred Island was a deeply-subsided site (approximately 16 feet below mean higher high water) when it breached in 1983. This 1993 infra-red photograph shows that limited perimeter vegetation (shown in red) established in the 10 years following breaching and that most of the site remains open water (shown in black).

Implications of the Conceptual Model for Restoration in the Sacramento-San Joaquin Delta

The conceptual model has the following implications for future Delta wetland restoration:

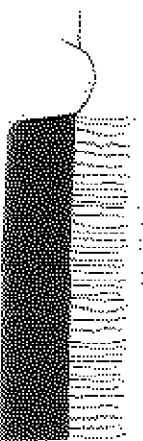
- **Shallowly-subsid sites.** Restoring tidal action to shallowly-subsid (intertidal) sites is expected to result in rapid re-establishment of a vegetated marshplain. Where the remnant channel system is intact, a natural network of drainage channels will also re-establish. Up to 100 to 200 years may be required to re-establish natural marshplain elevations at mean higher high water.
- **Deeply-subsid sites and natural sedimentation.** Natural sedimentation and organic accumulation cannot be relied upon to build marshplain elevations to intertidal elevations for the type of deeply-subsid, high wind fetch conditions typically encountered in the central Delta. Limiting wave action and wind-driven currents may be an effective way of speeding the rate of natural sedimentation, although this method is untested.
- **Deeply-subsid sites and beneficial reuse of dredge material.** Beneficial reuse of dredged material is a promising technique for restoring vegetated marsh to deeply-subsid sites. Creation of ecologically-valuable tidal channel habitat, however, requires special design consideration, such as grading during construction or creation of the appropriate conditions for natural tidal action to scour channels.

ENDPOINT

INTERMEDIATE

NEW ENDPOINT

subsoil for Lower
Mandeville Tip and planted
Prospect Island restoration



highly the marsh

NOT OBSERVED
IN THE DELTA



LEGEND



tide peat soil



subtidal
accumulation



dredged material



upland soil fill



tulle



submerged aquatic
vegetation

MLLW

mean lower
low water

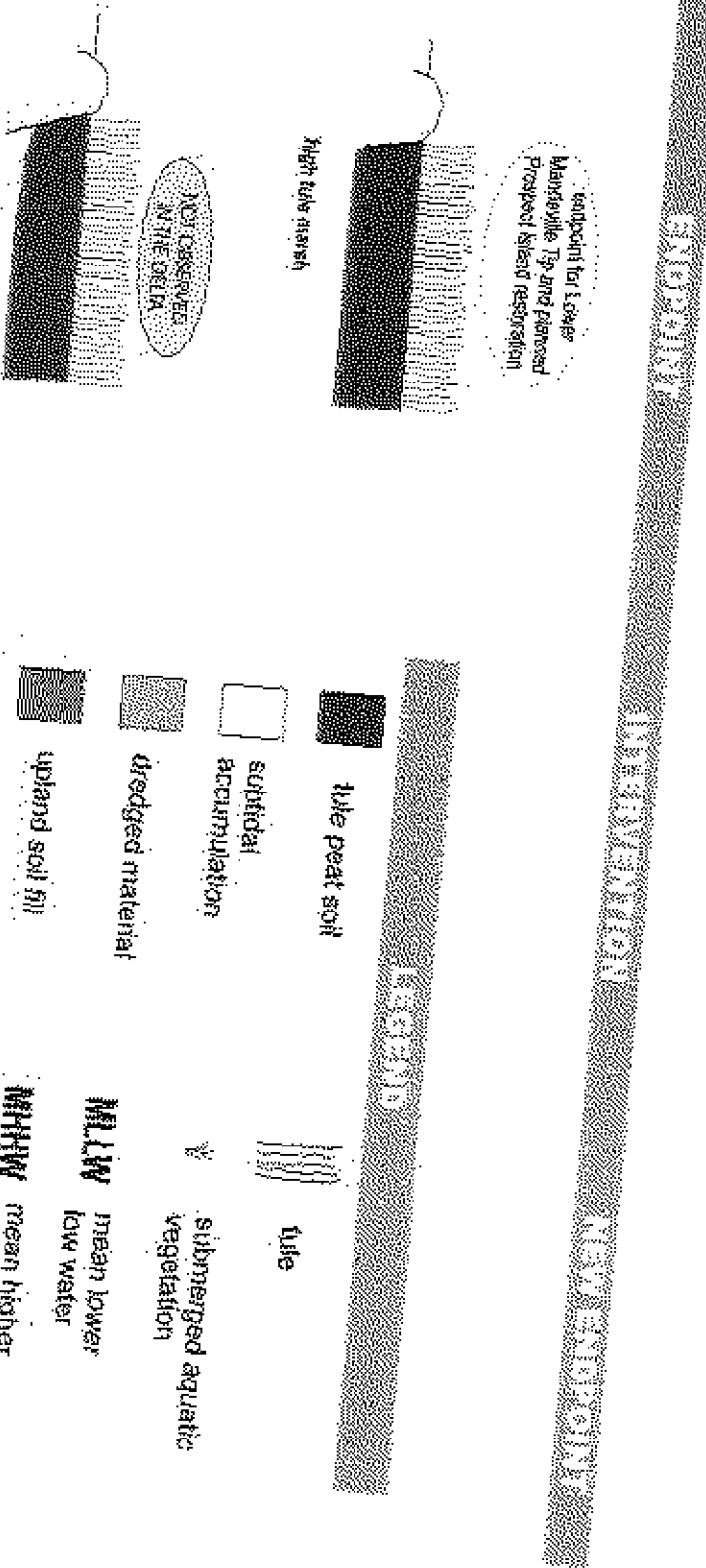
MHHW

mean higher
high water

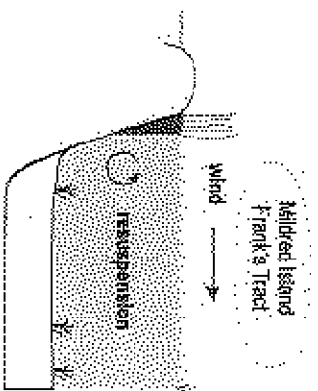
Implications of the Conceptual Model for Restoration in the Sacramento-San Joaquin Delta

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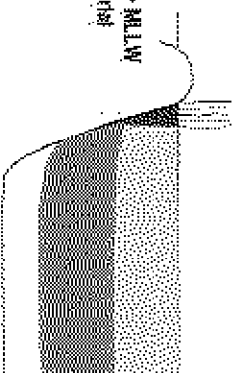
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- **Deeply-subsided sites and beneficial reuse of dredge material.** Beneficial reuse of dredged material is a promising technique for restoring vegetated marsh to deeply-subsided sites. Creation of ecologically-valuable tidal channel habitat, however, requires special design consideration, such as grading during construction or creation of the appropriate conditions for natural tidal action to scour channels.



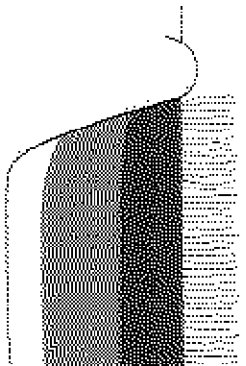
subtidal accumulation and
intertidal tube peat formation



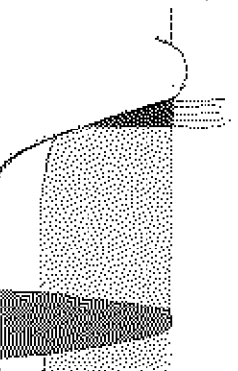
raise elevation to > MLLW
with dredged material



Parts of Donlon Island
and Venice Cut



limit energy
to allow
subtidal
accumulation
to MLLW



new subtidal
accumulation

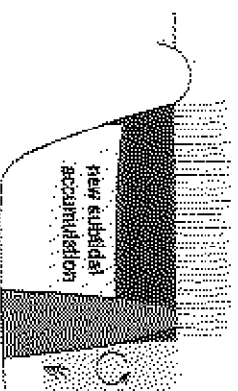


Figure 6 Donlon Island.

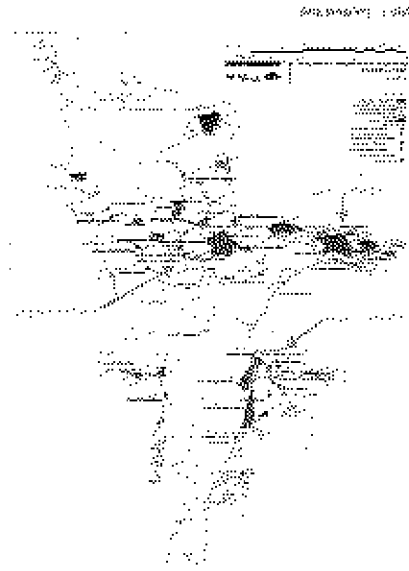
Donlon Island is a breached-levee site that has been fully tidal since 1937. Nine dredged material islands were created at Donlon Island in 1985 as part of a beneficial re-use effort. Initial colonization of bare soil occurred rapidly for approximately the first two to three years, then slowed or stopped (USFWS and USACE 1990). This photograph was taken in 1997.



ACKNOWLEDGMENTS: The research upon which this poster is based was funded by Category III. We wish to thank Charles Simenstad at the University of Washington for his assistance in developing the conceptual model and for providing graphics support for this poster and Michelle Stevens of the University of California at Davis for her vegetation expertise.

REFERENCES: U.S. Fish and Wildlife Service Sacramento (USFWS) and U.S. Army Corps of Engineers Sacramento District (USACE). 1990. Design and Biological Monitoring of Wetland and Riparian Habitats Created with Dredged Materials. Deep Water Ship Channel Monitoring Program.

The purpose of this study was to determine the rates of sedimentation in the wetlands of the Sacramento-San Joaquin River Delta. The study was conducted in the Delta, which is a large area of wetlands in California. The Delta is one of the most important wetlands in the world, and it is home to many species of birds and fish. The Delta is also a major source of water for the state of California. The study was conducted in the Delta, which is a large area of wetlands in California. The Delta is one of the most important wetlands in the world, and it is home to many species of birds and fish. The Delta is also a major source of water for the state of California.



Sampling Design

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Methods

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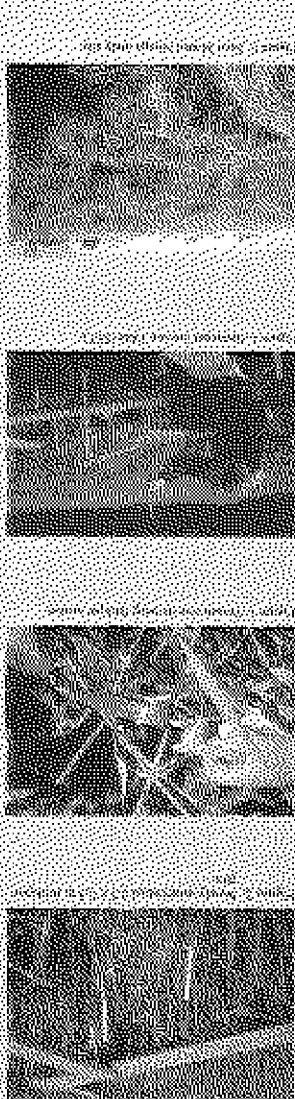


Figure 1: Aerial view of the wetlands. Figure 2: Close-up view of the water and vegetation. Figure 3: Dense forest of trees. Figure 4: Close-up view of the water and vegetation.

THE EFFECT OF THE EXOTIC AQUATIC PLANT E

THE FISH/INVERTBRATE FOOD WEB IN THE SA

Jason Toff, Charles Simenstad, and Jeffery Cordell, Wetland Ec



FIG. 1. Map of study area.



METHODS:
The study area was divided into three main sections: the E. zone, the native plant zone, and the control zone. The E. zone was defined as the area where E. was present in densities greater than 100 plants per square meter. The native plant zone was defined as the area where native plants were present in densities greater than 100 plants per square meter. The control zone was defined as the area where neither E. nor native plants were present in densities greater than 100 plants per square meter. The study area was divided into three main sections: the E. zone, the native plant zone, and the control zone. The E. zone was defined as the area where E. was present in densities greater than 100 plants per square meter. The native plant zone was defined as the area where native plants were present in densities greater than 100 plants per square meter. The control zone was defined as the area where neither E. nor native plants were present in densities greater than 100 plants per square meter.

RESULTS AND DISCUSSION:

The results of the study showed that the presence of E. had a significant negative effect on the fish/invertebrate food web. The density of E. was negatively correlated with the density of native plants, and the density of E. was positively correlated with the density of the exotic plant. The density of E. was also positively correlated with the density of the exotic plant. The density of E. was also positively correlated with the density of the exotic plant.

CONCLUSIONS:

The study concluded that the presence of E. had a significant negative effect on the fish/invertebrate food web. The density of E. was negatively correlated with the density of native plants, and the density of E. was positively correlated with the density of the exotic plant. The density of E. was also positively correlated with the density of the exotic plant.

ACKNOWLEDGMENTS:

The authors would like to thank the following people for their assistance in the study: [List of names]

LITERATURE CITED:

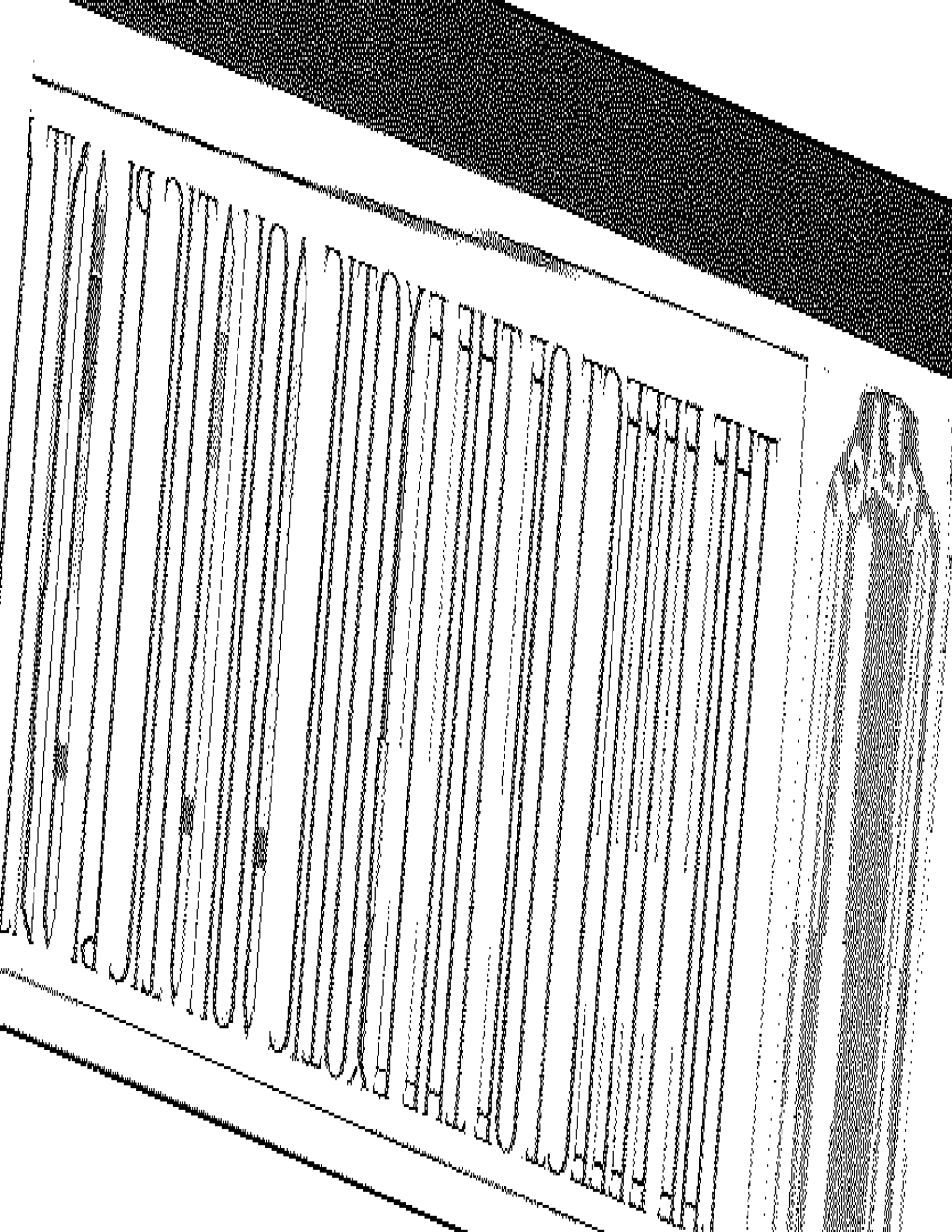
[List of references]

APPENDIX:

[List of data]

FIGURE 1:

[Figure description]





THE EFFECT OF THE EXOTIC AQUATIC PLANT *E. CRASSIPES* ON THE FISH/INVERTEBRATE FOOD WEB IN THE SACRAMENTO-SAN JOAQUIN DELTA

Jason Toft, Charles Simenstad, and Jeffery Cordell. Wetland Ecology



FIG. 1 *E. crassipes*, Water Hyacinth.

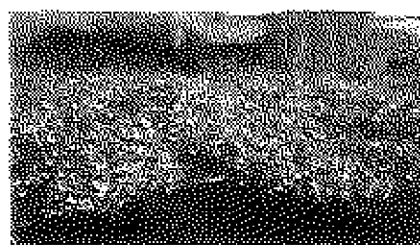


FIG. 3 Patch of *E. crassipes* along the marsh fringe

ABSTRACT:

Eichhornia crassipes (Water Hyacinth) is a floating aquatic macrophyte that was introduced into the Sacramento-San Joaquin Delta region in the 1940's. *E. crassipes* is native to Brazil, and has a history of worldwide invasions. Its international prominence, detrimental economic impacts, and associated management challenges makes it an important research focus. A common native plant that functionally occupies the same habitat as *E. crassipes* in the Delta is *Hydrocotyle umbellata* (Pennywort). Both plants are abundant in shallow water areas of the central Delta, although the Department of Boating and Waterways controls abundance of *E. crassipes* with chemical spraying of 2, 4-D. The relative effect on community dynamics of *E. crassipes* as compared to its suitable native counterpart, *H. umbellata* is unknown. It is expected that invertebrate taxa richness and density will be different between the two vegetation types, due to distinct physical and biological characteristics of the canopies.

As part of the BREACH research program (see BREACH position) and in conjunction with collaborating DWR research on fish assemblages in shallow water habitats, we are investigating food web linkages between invertebrate prey associated with *E. crassipes* and *H. umbellata*. Additionally, we are measuring vegetation patch size and dissolved oxygen levels. Both plants have diverse invertebrate assemblages in their root spaces, dominated by amphipods. Fish diet analyses show that these amphipods provide food for fish in the area. We are also characterizing the insects in the above-water canopy of the two plants, and the benthic invertebrate communities. Dissolved oxygen levels show a marked decrease underneath *E. crassipes*, as compared to underneath *H. umbellata* and next to emergent vegetation.

INTRODUCTION:

The invasion of *E. crassipes* has caused a heated and controversial over issues of control and management. By the 1980's, its abundance became a hindrance to boat traffic. Chemical control of *E. crassipes* currently has an annual cost of approximately \$1,000,000 (see Thakum, personal communication). Biological invaders such as *E. crassipes* have become widespread on a global level. Exotic species can alter the population dynamics and community structure of native ecosystems and are primarily successful in disturbed habitats. This is especially important in the Sacramento-San Joaquin Delta, as the San Francisco Bay area is considered the major estuary in the United States most modified by human activity (Nichols et al. 1986), and may be the most invaded estuary in the world (Cohen and Carlton 1998).

Research elsewhere in the world has shown that the roots of *E. crassipes* can be important habitat for epibenthic macroinvertebrates, mainly amphipods (Clopai 1987). Floating aquatic vegetation (FAV) can also be beneficial as a nursery habitat for juvenile fishes, as well as many invertebrates. This is often dependent on patch size, as large patches of *E. crassipes* can cause low dissolved oxygen, high detritus production, and succession of submerged vegetation (Clopai 1987). The effects of *E. crassipes* on community dynamics as compared to its native functional counterpart has not been studied in the Delta, and little examined elsewhere. The native *Hydrocotyle umbellata* (Pennywort) functionally occupies the same habitat as *E. crassipes* in the Delta. It is expected that invertebrate taxa richness and density will be different between the two vegetation types, due to changes in: (1) spatial complexity of the vegetation structures (Figs. 1, 2, 3), (2) shading effects of dense canopies, (3) amount and location of plant biomass, (4) densities of vegetation patches, (5) plant detritus deposition rate, (6) growth rates, (7) dissolved oxygen levels, and (8) rates of evapotranspiration (Clopai 1987). Effects on the fish/invertebrate predator-prey food web are particularly unknown, and are of importance due to the persistence of FAV as a major barrier zone in this food web.

OBJECTIVES:

- (1) Characterize the assemblages of macroinvertebrates in the roots, benthic macroinvertebrates, and terrestrial insects associated with *E. crassipes* and *H. umbellata*.
- (2) Characterize the resident fish assemblages and food web pathways.
- (3) Characterize physical measurements of dissolved oxygen and water flow.

METHODS:

Study Sites We are studying 3 sites in the Delta, which are a subset of the 10 study sites involved in the BREACH research program (Fig. 4). Site A was sampled in June of 1998, and Sites B and C were sampled in August of 1998. All vegetation patches are located on the marsh fringe, and are medium in size. Length and width measurements of the FAV canopy are taken at each patch.

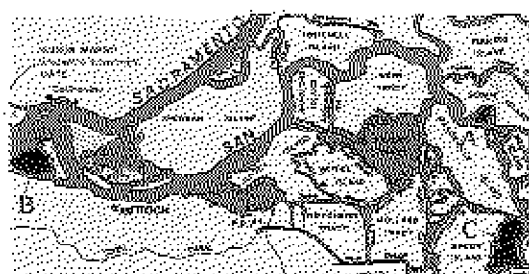


FIG. 4 Map of study sites.

Biological Sampling

- (1) Epibenthic invertebrates living in the root masses of the vegetation are sampled by manually collecting plant samples. Macroinvertebrates are then separated from the collected root mass by immersing the root mass into a bucket containing 100% ethanol. Canopy surface area is determined by correlating the number of leaves in each plant sample to the number of leaves in a 0.5 m² quadrat.
- (2) Benthic invertebrates are sampled with a 2-inch diameter core to a depth of 10 cm. Sampling is also conducted at nearby emergent tule (*Scirpus* sp.) and riparian patches when present.
- (3) Insect fallow traps are used to sample the terrestrial insects living in the vegetation canopy. These traps consist of a rectangular tray (35 cm x 38 cm) filled with soapy water. The trays are tethered to PVC pipes at each site, allowing vertical movement with the tides. The trays are collected after 24 hours. Sampling is also conducted at nearby emergent tule (*Scirpus* sp.) and riparian patches when present.
- (4) Seine-netting is used to sample fish underneath FAV. Although not presented in this report, the Department of Water Resources (DWR) also is sampling fish in shallow water areas adjacent to FAV using seine netting used jointly by Cordell et al. Fish are saved for diet analyses. Prey items are ranked based on modified ISI Guides of Relative Importance values. Fish overlap with invertebrates is calculated using the PSI (Percent Similarity Index), with a value of 100 showing complete overlap.

Physical Sampling Measurements of dissolved oxygen and patch size are taken at each FAV patch.

RESULTS AND DISCUSSION:

Biological Sampling

- (1) Epibenthic Invertebrates in the Roots: The amphipods *Corophium floridanum*, *Hyalella monticola*, and *Gammarus subtypicus*, and the isopod *Ceratonereis acronotus* are the most abundant taxa overall (Fig. 5; see Box A for a description of amphipods and isopods, many of which are introduced and/or first records for the Delta). Richness is specific for each site, and shows differences in invertebrate communities between *E. crassipes* and *H. umbellata*. For example, at Site A the major species is the introduced *C. floridanum* at *E. crassipes*, and the native *H. subtypicus* at *H. umbellata*. Taxa richness and the Shannon-Weiner Diversity Index are higher for *H. umbellata* in June (Site A), but higher for *E. crassipes* in August (Sites B and C; Table 1). This correlates with the peak bloom of *H. umbellata* in June, and the peak bloom of *E. crassipes* in August.
- (2) Benthic Invertebrates: Oligochaetes represent the most abundant taxa overall (Fig. 6). In June (Site A), taxa richness and the Shannon-Weiner Diversity Index are much higher for FAV than for emergent and riparian strata (Table 1). However, in August (Site B), taxa richness in *E. crassipes* is equal with that for the emergent strata, while *H. umbellata* still has high values. This is presumably due to the high plant detritus deposition rate associated with *E. crassipes*. Most of the additional taxa in the FAV represent fall-out amphipods and bryozoans from the overlying root mass community.
- (3) Terrestrial Insects in the Vegetation Canopy: Chironomidae and Culicidae represent the most abundant taxa overall for June (Fig. 7). The abundance of Culicidae in *H. umbellata* patches is the major difference with *E. crassipes*. Measurements of taxa richness and the Shannon-Weiner Diversity Index are similar for FAV, and are both higher than emergent and riparian strata (Table 1).
- (4) Fish: Numbers and average lengths for all fish captured in five seine-net samples (adjacent to the separate patches of *E. crassipes* at site C) are as follows: 6 juvenile Bluegill (*Lepomis macrochirus*), 75.83 mm; 24 small juvenile Bluegill (*Lepomis macrochirus*), 25.23 mm; 18 juvenile Largemouth Bass (*Micropterus dolomieu*), 51.89 mm; 5 Rainbow Shiner (*Notropis cornutus*), 28.60 mm; and 2 Brown Bullheads (*Ictalurus nebulosus*), 35.9 mm. All of these fish are non-native to the Delta. Other common taxa included the crayfish *Procambarus clarkii* and the giant water bug *Belostomatidae*. Figure 8 illustrates a representative ISI for *Lepomis macrochirus*. A PSI value of 64.36 with prey invertebrates in the root mass shows that these fish are feeding mainly on the amphipods, isopods, zygoptera nymphs, and chironomidae larvae in the overlying root mass. The remainder of the prey is planktonic copepods, cladocerans, and ostracods. Site C was the only site sampled in this manner, as the water was too deep at all other sites. However, sampling by DWR in shallow water areas adjacent to the FAV patches has produced additional fish data. Diet analyses on these samples illustrates similar trends in prey frequency.

Physical Sampling At site B dissolved oxygen levels are significantly lower underneath both FAV patches than at emergent strata, with *E. crassipes* having a slightly lower value than *H. umbellata* (Fig. 9). At site C, *E. crassipes* has a lower value than emergent strata, but *H. umbellata* has a much higher value. This could again be due to the high plant detritus deposition rate associated with *E. crassipes*. Average FAV patch area for all sites was 30.28 m², except for the *H. umbellata* patches at Site A, which measured along the marsh edge and did not have a strictly defined boundary.



THE EFFECT OF THE EXOTIC AQUATIC PLANT *E. crassipes* ON THE FISH/INVERTEBRATE FOOD WEB IN THE SACRAMENTO-SAN JOAQUIN DELTA

Jason Toft, Charles Simenstad, and Jeffery Cordell, Wetland Ecology and Management Center, University of California, Davis, CA 95616



FIG. 1. *Eichhornia crassipes*, Water Hyacinth.

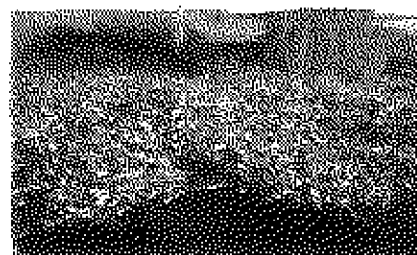


FIG. 3. Patch of *E. crassipes* along the marsh fringe.

ABSTRACT:

Eichhornia crassipes (Water Hyacinth) is a floating aquatic macrophyte that was introduced into the Sacramento-San Joaquin Delta region in the 1940's. *E. crassipes* is native to Brazil, and has a history of worldwide invasions. Its international proliferation, detrimental economic impacts, and associated management challenges makes it an important research focus. A common native plant that functionally occupies the same habitat as *E. crassipes* in the Delta is *Hydracote umbellata* (Pennywort). Both plants are abundant in shallow water areas of the central Delta, although the Department of Boating and Waterways controls abundance of *E. crassipes* with chemical spraying of 2,4-D. The relative effect on community dynamics of *E. crassipes* as compared to its suitable native counterpart *H. umbellata* is unknown. It is expected that invertebrate tax richness and density will be different between the two vegetation types, due to distinct physical and biological characteristics of the canopies.

As part of the BREACh research program (see BREACh poster) and in conjunction with collaborating DWR research on fish assemblages in shallow water habitat, we are investigating food web linkages between invertebrate prey associated with *E. crassipes* and *H. umbellata*. Additionally, we are measuring vegetation patch size and dissolved oxygen levels. Both plants have diverse invertebrate assemblages in their root masses, dominated by amphipods. Fish diet analyses show that these amphipods provide food for fish in the area. We are also characterizing the faunas in the above-water canopy of the two plants, and the benthic invertebrate communities. Dissolved oxygen levels show a marked decrease within dense *E. crassipes*, as compared to non-dense *H. umbellata* and next to emergent vegetation.

INTRODUCTION:

The invasion of *E. crassipes* has caused a number of disturbances over issues of control and management. By the 1980's, its abundance became a hindrance to boat traffic (Chemical control of *E. crassipes* currently has an annual cost of approximately \$1,200,000 (Van Thullen, personal communication). Biological invaders such as *E. crassipes* have become widespread on a global level. Exotic species can alter the population dynamics and community structure of native ecosystems, and are primarily successful in disturbed habitats. This is especially important in the Sacramento-San Joaquin Delta, as the San Francisco Bay area is considered the major estuary in the United States most modified by human activity (Nelson et al. 1986), and may be the most invaded estuary in the world (Cohen and Carlton 1998).

Research elsewhere in the world has shown that the roots of *E. crassipes* can be important habitat for epibenthic macroinvertebrates, mainly amphipods (Cipol 1987). Floating aquatic vegetation (FAV) can also be beneficial as a nursery habitat for juvenile fishes, as well as many invertebrates. This is often dependent on patch size, as large patches of *E. crassipes* can cause low dissolved oxygen, high methyl production, and senescence of submerged vegetation (Cipol 1987). The effects of *E. crassipes* on community dynamics as compared to its native functional counterparts has not been studied in the Delta, and little examined elsewhere. The native *Hydracote umbellata* (Pennywort) functionally occupies the same habitat as *E. crassipes* in the Delta. It is expected that invertebrate tax richness and density will be different between the two vegetation types, due to changes in: (1) spatial complexity of the vegetative structures (Figs. 1, 2, 3), (2) standing effects of dense canopies, (3) amount and location of plant biomass, (4) densities of vegetation patches, (5) plant debris deposition rate, (6) growth rates, (7) dissolved oxygen levels, and (8) rates of evapotranspiration (Cipol 1987). Effects on the fish/invertebrate predator-prey food web are particularly unknown, and are of importance due to the persistence of FAV as a major habitat zone in this food web.

OBJECTIVES:

- (1) Characterize the assemblages of invertebrates in the roots, benthic macroinvertebrates, and terrestrial insects associated with *E. crassipes* and *H. umbellata*.
- (2) Characterize the resident fish assemblages and food web pathways.
- (3) Characterize physical measurements of dissolved oxygen and patch size.

METHODS:

Study Sites We are studying 3 sites in the Delta, which are a subset of the 10 study sites involved in the BREACh outreach program (Fig. 4). Site A was sampled in June of 1998, and Sites B and C were sampled in August of 1998. All vegetation patches are located on the marsh fringe, and are medium in size. Length and width measurements of the FAV canopy are taken at each patch.

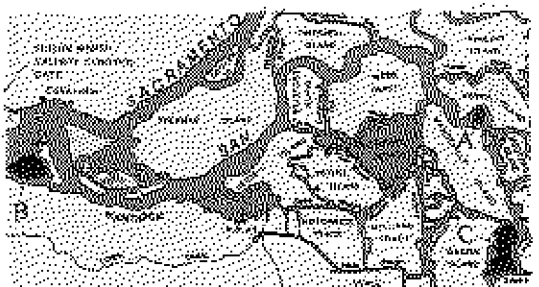


FIG. 4. Map of study sites.

Biological Sampling:

- (1) Epibenthic invertebrates living in the root masses of the vegetation are sampled by manually collecting plant samples. Macroinvertebrates are then separated from the collected root mass by quartering the root mass into a bucket containing 10% ethanol. Canopy surface area is determined by overlying the number of leaves in each plant sample to the number of leaves in a 0.5 m² quadrat.
- (2) Benthic invertebrates are sampled with a 2-inch diameter core to a depth of 10 cm. Sampling is also conducted at nearby emergent tule (*Scirpus* sp.) and riparian patches when present.
- (3) Insect fallow traps are used to sample the terrestrial insects living in the vegetation canopies. These traps consist of a rectangular tray (53-cm x 10-cm) filled with soapy water. The trays are secured in PVC pipes at each site, allowing vertical movement with the tides. The trays are collected after 24 hours. Sampling is also conducted at nearby emergent tule (*Scirpus* sp.) and riparian patches when present.
- (4) Seine netting is used to sample fish underneath FAV. Although not presented in this report, the Department of Water Resources (DWR) also is sampling fish in shallow water areas adjacent to FAV using seine netting (see poster by Ceinalde et al.). Fish are saved for diet analysis. Prey items are ranked based on modified IRI (Index of Relative Importance) values. Diet overlap with invertebrates is calculated using the PSI (Percent Similarity Index), with a value of 100 showing complete overlap.

Physical Sampling Measurements of dissolved oxygen and patch size are taken at each FAV patch.

RESULTS AND DISCUSSION:

Biological Sampling

- (1) Epibenthic Invertebrates in the Roots: The amphipods *Crangonyx floridanus*, *Hyalella aspera*, and *Gammarus* sp. and the isopod *Ceriodonte monochyla* are the most abundant taxa overall (Fig. 5; see Box A for a description of amphipods and isopods, many of which are introduced and/or first records for the Delta). Results are specific for each site, and signify differences in invertebrate communities between *E. crassipes* and *H. umbellata*. For example, at Site A the major species is the introduced *C. floridanus* in *E. crassipes*, and the native *H. aspera* in *H. umbellata*. Taxa richness and the Shannon-Weiner Diversity Index are higher for *H. umbellata* in June (Site A), but higher for *E. crassipes* in August (Sites B and C; Table 1). This correlates with the peak bloom of *H. umbellata* in June, and the peak bloom of *E. crassipes* in August.

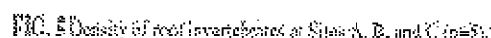
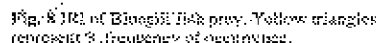
- (2) Benthic Invertebrates: Oligochaetes represent the most abundant taxa overall (Fig. 6). In June (Site A), taxa richness and the Shannon-Weiner Diversity Index are much higher for FAV than for emergent and riparian strata (Table 1). However, in August (Site B), taxa richness in *E. crassipes* is equal with that for the emergent strata, while *H. umbellata* still has high values. This is presumably due to the high plant debris deposition rate associated with *E. crassipes*. Most of the additional taxa in the FAV represent fall-out amphipods and isopods from the overlying root mass community.

- (3) Terrestrial Insects in the Vegetation Canopy: Chironomidae and Coleoptera represent the most abundant taxa overall for June (Fig. 7). The abundance of Chironomidae in *H. umbellata* patches is the major difference with *E. crassipes*. Measurements of taxa richness and the Shannon-Weiner Diversity Index are similar for FAV and are both higher than emergent and riparian strata (Table 1).

- (4) Fish: Numbers and average lengths for all fish captured in five separate patches of *E. crassipes* at site C are as follows: 6 juvenile Bluegill (*Lepomis macrochirus*), 75.83 mm; 24 small juvenile Bluegill (*Lepomis macrochirus*), 25.25 mm; 18 juvenile Largemouth Bass (*Micropterus niloticus*), 51.80 mm; 5 Rainwater Killifish (*Cachia pinnata*), 38.80; and 2 Brown Bullheads (*Amblopterus nebulosus*), 184.0 mm. All of these fish are native to the Delta. Other common taxa included the crayfish *Procambarus clarkii* and the giant water bug *Belostomatidae*. Figure 8 illustrates a representative IRI for *Lepomis macrochirus*. A PSI value of 61.36 with prey invertebrates in the root mass shows that these fish are feeding mainly on the amphipods, isopods, cyclopoid nauplii, and chironomid larvae in the overlying root mass. The remainder of the prey is planktonic copepods, cladocerans, and ostracods. Site C was the only site sampled in this manner, as the water was too deep at all other sites. However, sampling by DWR in shallow water areas adjacent to the FAV patches has produced additional fish data. Diet analyses on these samples illustrate similar trends in prey feeding.

Physical Sampling At site B dissolved oxygen levels are significantly lower underneath both FAV patches than in emergent strata, with *E. crassipes* having a slightly lower value than *H. umbellata* (Fig. 9). At site C, *E. crassipes* has a lower value than emergent strata, but *H. umbellata* has a much higher value. This could again be due to the high plant debris deposition rate associated with *E. crassipes*. Average FAV patch area for all sites was 22.20 m², except for the *E. crassipes* patches at Site A, which maintain a long narrow shape and did not have a strictly defined boundary.

INTEGRATES IN ROOTS PER 1.0 M²

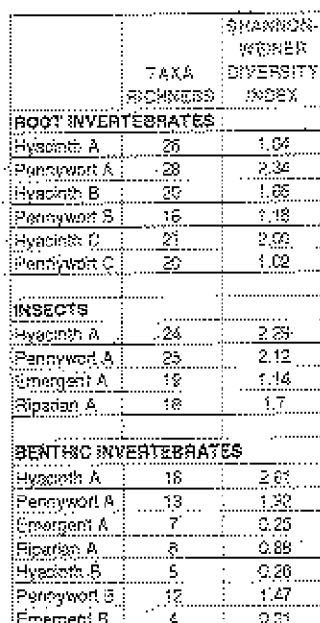
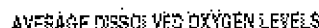
 $\bar{p}(K)$: # Density of benthic invertebrates at Sites A and B ($n=50$)SITE C: *E. crassius* BLUEGILL IN

Cohen, A. N., and Carlsberg, J. T. 1978. Accelerating invasion rate in a highly invaded estuary. *Science* 179:555-558.

Gopal, K. 1987. *Aquatic Plant Studies I*. Water Hyacinth. Elsevier publishing, 371 pp.

Nichols, F. H., Cloern, J. E., Luoma, S. N., and Peterson, D. H. 1986. The modification of an estuary. *Science* 231: 567-575.

Thalbert, P. Personal Communication. Water Hyacinth Control, DOW.

FIG. 2. *Neolarentia uncinata*, head viewed.

Site	Emergent (mg/L)	Headwater (mg/L)	Pioneers (mg/L)
SITE A	6.5	5.5	7.5
SITE B	4.5	3.5	5.5
SITE C	5.5	4.5	6.5

FIG. 7. Density of insecticide-resistant (IR) aphid species per 100 plants for four habitats. Error bars represent 1 standard deviation.

Prey Item	% Frequency of Occurrence
Concharia nympha	~30
Hydrilla azteca	~25
O. insularis	~10
Characrinidae	~15
Serranophilus sp.	~10
Caridiophora sp.	~15
Crangon floridanus	~10
P. kribbi	~30
Cladocera A	~10
Cyclopoida	~30
Ostracoda	~10

Fig. 4. (B) of Bluegill fish prey. Y-axis represent % frequency of occurrence.

CONCLUSION-

It is apparent that *E. crassispes* has had a remarkable impact on nearshore habitats in the Sacramento-San Joaquin Delta, as well as in many other areas throughout the world. The invertebrate communities associated with *E. crassispes* are often unique from the native *H. undulatus*. The invertebrates living in the mud mass serve as prey for resident non-native fish. These mud mass invertebrates consist mostly of amphipods and isopods, many of which are introduced. It is open to speculation whether some of these crustaceans may have arrived into the Delta via the roots of *E. crassispes*. All fish sampled underneath canopies of *E. crassispes* were juveniles, so it appears that fish use *E. crassispes* as both a refuge habitat and food resource. *E. crassispes* can have a detrimental effect on the underlying benthic community as compared to *H. undulatus*, due to high plant detritus deposition rate and low dissolved oxygen levels. Consistent with the high monetary value placed on controlling the spread of *E. crassispes*, such preliminary findings warrant more research on the role of *E. crassispes* in the nearshore community.

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